State of the Art: LCA in the Nordic Region

Status of Life Cycle Assessment (LCA) Activities in the Nordic Region

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Abstract. The status of Life Cycle Assessment (LCA) activities in the Nordic Region (period 1995-97) is presented, based on more than 350 reported studies from industrial companies and research institutes in Sweden, Denmark, Norway, and Finland. A large number of industrial sectors is represented, with car components, building materials, pulp and paper products, electronic components and packaging as the most important ones. All aspects of LCA methodology are used: 90% use impact assessment, 80% impact assessment and valuation step. In most studies, more than one valuation method is used for ranking environmental impacts.

LCA studies are well integrated in the business activities in many large Nordic corporations. From the early attempts, more familiar with LCA methodology, LCA has been integrated in strategy development, product development, process development and, to some extent, marketing. LCA has not only been used in the strict sense presented in the ISO 14040-43 standards. The systems approach, which is the basis for LCA, has also been modified and used in Sustainable Product Development, and in Environmental Performance Indicator and Product Declarations development. Future applications should be within Environmental Impact Assessments.

Keywords: Applications; industrial sectors; LCA software systems; Life Cycle Assessment (LCA); methodology; nordic region; status report

1 Introduction

Life Cycle Assessment (LCA) is a relatively new method within environmental management, directed towards a product-oriented environmental strategy in industry, and in business sector and governmental policies. The "modern" history of LCA started in the late 1980s, when SETAC (Society for Environmental Toxicology and Chemistry) initiated the framework for the development and harmonisation of LCA methodology. Several workshops have been carried out, with comprehensive reports documenting the main findings and conclusions.

The Nordic region has been among the front leaders in LCA application and method development. The Nordic Council of Ministers started an LCA program in 1991, with a report on the state of the art of LCA activities in 1992 (NORD, 1992). In this report, one chapter was dedicated to a comprehensive overview of LCA studies (PEDERSEN & CHRISTENSEN, 1992). The main focus of these studies was first of all increased knowledge about LCA methodology and comparisons between environmental profiles of product alternatives (HANSSEN, 1993). After this pilot report, a methodological project was carried out in the period 1993-95, with several case projects to test alternative methodological aspects. This work was documented in three reports in 1995; two methodological studies (LINDFORS et al., 1995a, b) and a Nordic LCA guideline (NORD, 1995).

Several large programs have been carried out during the last three years, both nationally and on a Scandinavian and Nordic level. Among the most important are:

- The Product Ecology Project where 12 large Swedish companies and one Norwegian company developed methods and carried out LCA case projects (RYDING, 1993).
- The Nordic project for Environmental Sound Product Development (NEP-project), where 22 large Nordic companies developed methods and carried out case projects with integrating LCA in product development (HANSSEN et al., 1995).
- The Environmental Development of Industrial Products (EDIP) project, where the Danish Environmental Protection Agency and the Confederation of Danish Industries together with five Danish companies developed LCA methods and databases, and carried out case projects in LCA application in product design (WENZEL et al., 1997; HAUSCHILD & WENZEL, 1998).
- Nordic LCA projects in the Cement and Concrete industry, where LCA data were gathered for products from each producer, comparisons were done with competing products and LCA was integrated with product development (VOLD & RØNNING, 1995).
- Nordic project for light constructions, with development of software tools for environmental design, and case projects in industry (MYKLEBUST et al., 1997).
- The Environmental Performance Indicator Project (EPI-project), where 12 Norwegian and Swedish companies tested methods for EPI development based on LCA of main products (ØKSTAD, 1997).
- The Danish project on product ranking according to life cycle energy consumption and resource loss, where all industrial products used in Denmark were covered (HANSEN, 1995).

Table 1: Overview of the number of LCA studies reported and institutions which have answered the questionnaire from the Nordic region

	Norway		Sweden		Denmark		Finland		Total
	Industry	Research institutes	Industry	Research institutes	Industry	Research institutes	Industry	Research institutes	
Number of LCA studies reported	42	59	93	58	5	71	0	20	348
Number of institutions	6	7	6	6	3	3	0	1	32
Number of studies per institution	7,0	8,4	15,5	9,7	1,7	23,7	0	20,0	10,9

All these projects are characterised by a very open collaboration between industrial companies, between industry and research institutes, which often have been the catalysing agent in the projects, and also between industry and environmental authorities. This has been an important basis for the large LCA activity in the Nordic region. As discussed by Baumann (1996), LCA, to a large extent, is integrated in the environmental business activities by a number of Nordic companies.

Ryding (1993), Karlson (1992) and Baumann (1996) have investigated the use of LCA by industrial companies.

2 Methods and Data Materials

The material which is the basis for this survey, has been gathered through a questionnaire to all participants in the Nordic LCA seminar in Oslo in October 1997 (see Rønning & Vold, 1997). The 70 participants covered most of the active research institutes, industrial companies and governmental agencies in the Nordic countries. In addition, about 10 contact persons in important LCA organisations not participating in the Nordic seminar were contacted.

The questionnaire was originally used as a preparation for a lecture on the status of LCA activities in the Nordic Region, on a two-day workshop on Product-Oriented Environmental Approaches organised by the Nordic Council of Ministers in Stockholm 21-22 January 1998 (Nordic Council of Ministers, 1998).

The questionnaire covered the total LCA activities in each organisation during the last three years. It has thus not been made any attempt to identify and describe each individual LCA study carried out. This is clearly a weakness of the study, as each contact person might classify and summarise the LCA studies differently.

The basic data material is presented in Tables 1 and 2. As shown in Table 1, about 350 LCA studies on specific products have been reported from 32 companies and research institutes in the Nordic region. Because many LCA studies include more than one product, the number of products studied is larger than the number of LCA studies.

Most questionnaires have been reported from Norway (13) and Sweden (12), whereas the number of LCA studies is fairly well distributed. The exception is Finland, where only one research institute is represented in the survey, with about 20 studies. This, however, is the most important one (VTT). About as many research institutes as companies have answered (15 companies and 17 research institutes). Most of the companies are large corporations which have carried out a large number of LCA studies (e.g. Volvo, Norsk Hydro), whereas quite a few represent the SME sector. The most experienced LCA research institutes in the Nordic region are all covered by the study. As far as possible, it has been checked out that no study has been reported twice by both a company and research institute or consultant.

A large proportion of the LCA studies from Norway and Sweden have been reported from industrial companies (about 42% and 62% respectively), whereas only 8% of the Danish studies are reported from industry (→ *Table 1*). This is probably a reflection of the great importance of the EDIP project in Denmark which has covered a large proportion of the LCA activity, and generated a number of following studies. It might, however, also be a reflection of a bias in the addresses of the questionnaires in Denmark, with an overrepresentation of research institutes.

In Table 2, the distribution of LCA studies on different industrial sectors is reported. Car components, building materials, pulp and paper products, electrical and electronic components and packaging are the most important product types. The survey covers both final products (e.g. electronics, chemicals, furniture, food products), raw materials and intermediate components (e.g. car components, building materials), and service products (e.g. transport).

Table 2: Product types represented in LCA studies in the Nordic countries

Product types	Norway	Sweden	Denmark	Finland	Total
Cars and car components	11	140	1	0	152
Building materials	41	4	1	10	56
Electric equipments/electronics	2	13	25	0	40
Paper and pulp mass	0	47	8	4	59
Packaging products	12	15	11	0	38
Buildings/large constructions	26	4	0	0	30
Chemicals, paints etc.	13	5	6	2	26
Other products	6	2	0	5	13
Total	111	223	52	21	414

Table 3: Main purpose of the LCA studies reported from Nordic countries (percent of total number of studies)

Main purpose of LCA studies	Norway	Sweden	Denmark	Finland	Total
Strategy development	7	18	8	25	13
Product development/improvement	23	42	31	0	32
Marketing/product comparisons	30	9	27	25	19
Governmental regulations	6	3	18	0	5
Increased knowledge of own product	20	16	3	25	15
Increased knowlegde of LCA	14	12	6	25	12
Development of LCA methodology	0	0	17	0	3
Total	100	100	100	100	100

Table 2 clearly shows that the distribution of the LCA studies on industrial sectors varies between the countries. This is partly due to the dominance of specific industrial sectors in each country, with car components and paper products, the dominant product types in Sweden (63% and 21% respectively of studies). It is probably also a reflection of the main interest related to the active LCA institutes in each country, e.g. the electronic sector in the activities of Institute of Product Design (IPU) in Denmark (48% of studies), and the studies of the Norwegian Building Research Institute (NBI) of building materials in Norway. Packaging is an important product type in all countries, reflecting the general interest in environmental studies on packaging materials and products by governmental agencies.

The LCA studies in the survey cover a relatively large proportion of the total number of LCA studies carried out in the Nordic region during the last three years: most of the well experienced companies and research institutes are covered by the study. The results should thus be fairly representative for the actual situation in the region.

3 Results from the Survey

3.1 Purpose of the LCA studies

The most important purposes of the LCA studies carried out in the Nordic region the three last years are shown in Table 3. Application in product development and improvement has been the single most important type of application, whereas marketing and comparisons between products are the second most important application. Application in strategy development for improving the knowledge about own products' environmental profile, and increased knowledge about LCA methodology are also applications of some importance. Governmental regulations, however, are of minor importance for the application of LCA studies in the Nordic region. These results reflect well the large industrial influence on the development and application of LCA during the past three years.

There are some important differences between the Nordic countries; they reflect both the history of LCA development and the activities promoted by national research centres. In Norway, most companies have reported to use LCA for increased knowledge about methodology and own products' environmental profile, which shows that LCA was later introduced here than, for instance, in Sweden. A large number of studies carried out by Østfold Research Foundation (STØ) for industrial partners have been focused on strategy development and product development, based on the methodology developed in the Nordic project on Environmental Sound Product Development (see HANSSEN et al., 1995). LCA studies carried out by NBI have first of all been focused on product comparisons (→ *Table 3*). Strategy development, and product development and improvement are the most important applications in Norway, Sweden and Denmark, probably due to the activities in the Product Ecology project (see RYDING, 1993) and the NEP project (HANSSEN et al., 1995) in Sweden, and the EDIP project in Denmark (WENZEL et al., 1997; HAUSCHILD & WENZEL, 1998). The EDIP project is also an important reason for the relatively large number of LCA studies related to development of methodology in Denmark (→ *Table 3*).

An overall experience is that companies use LCA actively in their strategy and product development processes in the Nordic region today, in order to develop business activities and products with better environmental profile than existing ones.

3.2 Methodology in LCA studies

The LCA methodological framework which has been described in SETAC publications and is internationally accepted as a framework in ISO 14040, consists of four main steps:

1. Goal and scope
2. Inventory analysis (LCI)
3. Impact assessment
4. Interpretation

The third step, impact assessment, is generally divided into three sub-steps:

- Classification
- Characterisation
- Valuation

Before 1995, most LCA studies ended by doing an inventory analysis, whereas only a few studies covered all three impact assessment sub-steps.

This survey shows that, since 1995, most of the LCA studies in the Nordic region have covered both inventory analysis and all three sub-steps of impact assessment (→ *Table 4*). More than 90% of all LCA studies in Norway and Sweden contained a quantification of environmental impacts (charac-

Table 4: Methodological differences in LCA studies between Nordic countries (percent of total number of studies)

Step in LCA included in studies	Norway	Sweden	Denmark	Finland	Total
Inventory step	100	99	86	100	97
Classification step	92	95	76	71	89
Characterization step	92	95	76	71	89
Valuation step	82	81	61	14	73

Table 5: Use of different valuation methods in LCA studies in Nordic countries (percent of total number of studies)

Valuation method included	Norway	Sweden	Denmark	Finland	Total
EPS-System	74	77	0	0	55
Effect category method	47	89	16	0	55
Ecoscarcity method	81	62	0	0	50
UMIP-methodology	0	0	62	0	12
Eco-indicator 95	29	32	0	0	22
Tellus	0	41	0	0	18

terisation), and more than 80% did also cover a valuation step. It is important to notice that the impact assessment step is limited to *potential* impacts in most or all studies, based on generic impact parameters from the Nordic Guidelines (NORD, 1995). Danish LCA studies, in general, covered fewer of the sub-steps than LCA studies from Norway and Sweden, mainly due to the tendency to use simplified ecoprofile matrices in early LCA studies (→ *Table 4*). The EDIP studies, however, consisted of all three steps of impact assessment. Very few Finish studies covered a valuation step, and about 30% were restricted to LCI studies.

3.3 Use of weighting methods

Several different weighting methods are globally available, and some have been adjusted to Nordic conditions. Magnussen et al. (1998) has given a comprehensive review of the different methods. In this survey, the respondents were asked to give an overview of which weighting methods have been applied for the different studies, and a percentage of the studies covered by the different methods. As shown in Table 5, a broad number of methods are used in Sweden and Norway, normally several methods in each study. The most important methods are the EPS system (RYDING & STEHEN, 1992), the Ecoscarcity method (AHBE et al., 1990) transformed to Nordic conditions (see BAUMANN, 1992; MAGNUSSEN et al., 1998), and the Environmental Theme method (BAUMANN & RYDBERG, 1994). The Tellus method has been used in nearly 50% of all Swedish studies, but has not been applied in Norway nor Denmark (→ *Table 5*). In Denmark the EDIP weighting method has been used in most studies, whereas few others have been applied at all (→ *Table 5*).

It seems that few if any LCA practitioners in the Nordic region rely solely on one specific weighting method, but use a number of methods and parameters in a given LCA study. The interpretations and conclusions from the studies will then often be a result from several methods, giving a range of priorities in the decision process. Such an approach has been promoted by Hanssen (1997) as a way to deal with the precautionary principle in product development.

3.4 Use of data tools

Today, several data tools are available for LCA practitioners. Several of these tools have been developed in the Nordic region, first of all Sweden and Denmark. The most important of the Nordic data tools are LCA Inventory Tools from Chalmers Industrial Technology in Gothenburg, Ecolab from Nordic Port Inc. also in Gothenburg, the EPS Software from Volvo, and the EDIP software from Institute of Product Development, the Life Cycle Centre in Copenhagen.

LCA Inventory tool is the most frequently applied software in the survey, with the EPS software as the second most important. This software, however, is mostly used by Volvo in their LCA studies. SimaPro, Ecolab and EDIP are all used in about 10% of the LCA studies (→ *Table 6*). The only international software package which has a place in the Nordic market, is Simapro from Prè in the Netherlands. This software tool is first of all in use in Norway, where no nationally developed software tool is available so far. The most important software tool in Norway, however, is LCA Inventory Tool from Sweden (→ *Table 6*). The same seems to be the case in Finland, although the data material is very small from this country. For the other countries, nationally developed software tools dominant to a high degree (→ *Table 6*).

4 Discussions and Conclusions

This survey clearly documents a high and co-ordinated LCA activity in the Nordic region during the last 3-5 years. More than 300 relatively comprehensive LCA studies have been carried out, mainly driven by large, international corporations like ABB (electric motors and equipments, etc.), Electrolux (whiteware products etc.), Volvo (car components), Stora (pulp and paper products), Tetra Pak (packaging products), Scancem (cement and concrete products), Norsk Hydro (metals and petrochemicals, etc.), Statoil (fuel products, etc.), Jotun (paints) and Bang & Olufsen (audiovisual products, etc.). This high LCA activity has been carried out in collaboration between industry and research institutes. In many programs, also environmental authorities have been actively involved (e.g. the EDIP-project). This has been an important basis for the active participation from the Nordic region in the development of LCA methodology through SETAC, and has also been the fundament for the integration of LCA in governmental and business policies.

Table 6: Use of different software tools in LCA studies in the Nordic countries (in percent of total number of studies)

Software tool	Norway	Sweden	Denmark	Finland	Total
LCA Inventory Tool	40	38	30	100	40
Ecolab	0	24	0	0	10
SimaPro	40	0	3	0	12
UMIP	0	0	42	0	9
EPS software	0	47	0	0	20
Others (spreadsheet etc.)	2	3	0	0	1

The Nordic LCA studies represent a good basis for empirical studies on methodological research themes, such as the four identified through the LCA Net project (UDO DE HAES & WRISBERG, 1997). A preliminary study on environmental profiles of product types, as a strategy to simplify LCA applications in the SME sector, has been presented by Hanssen (1997, 1998).

This survey gives clear indications that today LCA is an important element in the environmental management activities of many large companies. LCA has first of all been used in internal studies, as a basis for product developments and improvements, for strategy development and for internal competence building. Several of the companies have worked systematically with LCA studies on their main product types, involved actively both suppliers and customers, and in some cases been able to show economic benefits from these activities. Electrolux, for instance, has used experiences from LCA to develop business plans and indicators, and has shown improved economic results based on such an approach (ØKSTAD, 1997 Business & Environment). Statoil and Jotun worked together to develop new industrial paints for the offshore sector based on LCA and the NEP methodology (see HANSSEN et al., 1995; RØNNING et al., 1995). Statoil has changed the maintenance strategies for their offshore activities based on the LCA approach, and has documented significant reductions in annual maintenance costs annually. In addition, environmental and health impacts are estimated to be reduced with about 50% throughout the life cycle (RØNNING et al., 1995). These experiences will clearly be of value for LCA research in decision making processes, identified as one of the high priority research themes in the LCA Net project (UDO DE HAAS & WRISBERG, 1997).

In many of the projects, LCA has not only been regarded as a strict method based on SETAC methodology and ISO standards 14040-43. A life cycle approach has been more and more important, where models are developed for product systems in a life cycle perspective. The models are then evaluated with respect to interactions with the environment and human health, but also with respect to economics and stakeholder interest. Examples of such approaches are the NEP project, where both Life Cycle Cost assessments and evaluation of customer requirements through Quality Function Deployment analysis have been integrated with the LCA methodology (HANSSEN et al., 1995). Another example is the Environmental Performance Indicator Project (EPI project), where Eco-efficiency indicators were developed based on LCA and stakeholder interest assessment (ØKSTAD, 1997).

5 Future Outlook

LCA in the Nordic region has, to a large extent, focused on the integration with decision-making processes in companies. LCA has been the basis for further development of tools and methods which are more specific tools in such processes (→ *Fig. 1*). The further steps from LCA in such a model are Sustainable Product Management models (see HANSSEN et al., 1995), EPI tools (ØKSTAD, 1997), Environmental Product Declarations (MØLLER et al., 1998), Environmental Life Cycle Impact Assessment (ELCIA) and finally Industrial Ecology as a network approach to environmental problems (HANSSEN, in prep.). The two last ones are the least developed so far, as the holistic life cycle model so far has not been integrated in traditional Environmental Impact Assessment studies.

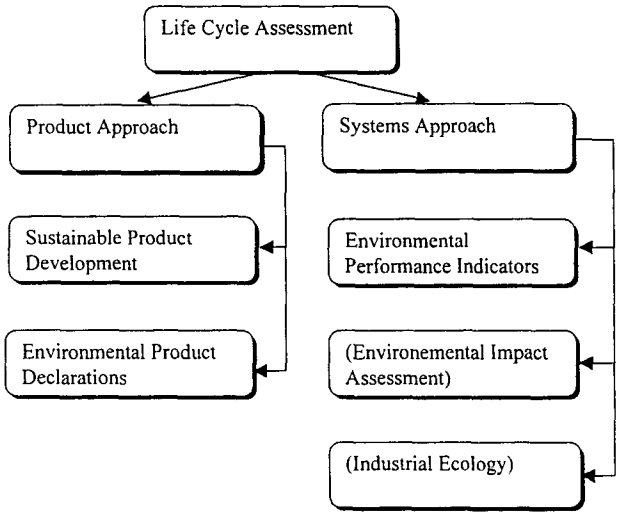

Fig. 1: Development in the application of Life Cycle Assessment methodology and approaches within Environmental Management Systems (Boxes in parantheses are not yet developed)

Altogether, these LCA-based tools and methods represent a systematic structure of a Total Environmental Management System. The structure of such a model, which is very similar to an economic management system, is shown in Fig. 2. LCA is first of all a tool for data gathering related to environmental impacts of products, in the same line as Pollution Prevention Assessment is a data gathering tool for environmental impacts of processes. These datas have to be systematically managed in the companies, in the same way as in economic accounting systems. This has to be done through data accounting systems and data bases which are on a level beyond traditional LCA software tools. From these databases, the companies can *communicate information* internally and externally through Environmental Performance Indicators with focus on organisations, or through Environmental Product Declarations with focus on specific products. Each of these communication tools is related to applications internally and externally in different ways, as indicated in Fig. 2.

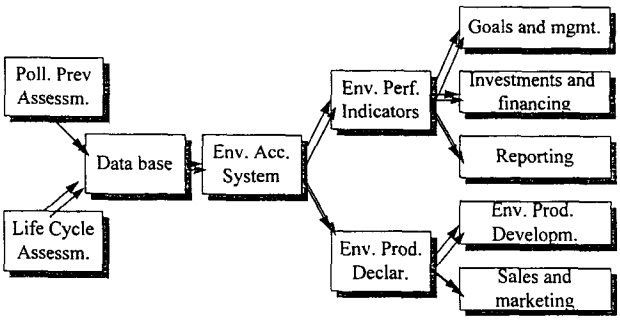

Fig. 2: Principle structure of the relationship between different Environmental ManagementTools and their applications in decision making and communication

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